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THE SOUTH PASS JETTIES.—TEN YEARS' PRACTICAL TEACHINGS IN RIVER AND HARBOR HYDRAULICS.

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Ten years ago, at this very time of the year, an earnest and heated controversy on the subject of improving the mouth of the Mississippi River was at its climax in Congress and in the public press. Two bills were before Congress—one containing the proposition of Mr. James B. Eads, M. Am. Soc. C. E., for improving the mouth of the river by means of jetties; the other, a bill presented through the Army Engineers for the construction of the Fort St. Philip Canal, leading from the river to the adjacent bay, about 40 miles above the mouth of the river. Hydraulic principles diametrically opposed to each other were presented by able advocates, and urged with all the force that could be brought to bear from facts, experience, prejudices and local interests.

The result was the appointment of a commission representing the U. S. Army Engineers, Civil Engineers, and the U. S. Coast Survey, which

was instructed to fully examine the subject, and report a plan at the next session of Congress. The civil engineers on that commission were Messrs. W. Milnor Roberts, M. Am. Soc. C. E., T. E. Sickles, M. Am. Soc. C. E., and H. D. Whitcomb, M. Am. Soc. C. E., all of whom, after careful examination of jetties in Europe, and an exhaustive study of the subject, favored and reported for an adoption of the jetty plan.

This plan was approved by the Government, and a contract entered into by it with Mr. Eads, the basis of which was that he was to make his own plans, was to be entirely untrammeled in their execution, and was to be paid only after securing the depths and widths of channel specified in the contract.

In a review of ten years' work, it is not possible to enter much into details, but to present salient points only; the object being particularly to give general results and the practical lessons taught by them.

The whole detailed and documentary history of the inception, construction and the results, up to July, 1879, are given in the history of the jetties published by the writer in 1880, to which reference is made for a more particular study of the subject, its conditions, the developments of the channels, and other results incident to the works.

The natural divisions of the subject are: The Work, The Results, The Lessons.

First.—The Work: Natural Conditions, Commercial Necessities, Fundamental Principles, Descriptions.

At New Orleans, 115 miles from the Gulf of Mexico, the Mississippi River is 150 feet deep and half a mile wide; at the head of the Passes, about 12 miles from the Gulf, the depths are over 30 feet in the two larger Passes, and 15 feet in the South Pass.

The depths *in* the Passes themselves were greater: 45 feet in the two larger Passes, and 30 feet in the South Pass; the latter carrying to the sea but 10 per cent. of the volume of the river.

The depths on the crest of the bars in the Gulf, outside of the land, were 13 feet at the Southwest Pass, 11 feet at Pass à Loutre, and 8 feet at the South Pass, all measured at mean low water.

The descent into the deep water of the Gulf off South Pass bar is very rapid, commencing with 1 foot in 60, and gradually flattening out so that 9 miles off the bar the depth is 600 feet; 25 miles off 3 000 feet, and farther out depths of 2½ miles can be found.

The volume of the river at the maximum flood is 1 210 000 cubic feet

per second; the low water discharge is about 250 000 cubic feet per second.

The amount of sedimentary matter transported in suspension each second at the flood stage is equal to 2 000 cubic feet of solid earth.

The annual extension of the bars into the Gulf at the mouths of the Passes before the construction of the jetties was 300 feet at Southwest Pass, 260 feet at Pass à Loutre, and 111 feet at South Pass.

The slopes and velocities of the river and passes, and the character of the bar at South Pass, on which the jetties are built, are given in detail in the history of the jetties. It is necessary to say here, in general, that "when the muddy waters leave the land's end at the mouth of the Passes, and begin to spread out over the submerged banks and shoals forming in advance, the current, which has all through the Passes flowed at a rapid and uniform rate in a deep and stable channel, gradually loses its velocity and drops its load of sediment. As the flow of the water expands more and more to the right and left, the depths in the channel going seaward continually decrease as the frictional resistance increases, until the crest of the bar is reached where the depth is the least. This upward slope going seaward at the South Pass was at the rate of 1 foot in 400.

"The Gulf into which the river pours its annual floods is a great inland sea of salt water. The range of the tides is very small, not averaging over 14 inches, and along the face of the delta they occur but once in a day. At flood river the fresh water pushes the salt water out of all the river channels and Passes, and away from the mouths of the Passes, even to the outermost crest of the bars, and then flows through a bed of salt water, gradually widening until it becomes a thin, light brown sheet, whose line of demarkation with the green salt water is clearly defined, and can be seen many miles from land. The river thus continually pushes out its bars into this almost tideless sea, which in turn, by its waves, tides and littoral currents, exerts a leveling and eroding influence upon them, especially in low water season."

One of the most important forces, affecting perhaps as much as any other the success of the jetty plan, and the permanence of the channel produced by the works, is the existence of the littoral or shore current at the mouth of the South Pass. The late Mr. G. W. R. Bayley, M. Am. Soc. C. E., the resident engineer of the jetties, states: "Modern current charts correctly represent the great equatorial current as sweep-

ing in its resistless course around the Gulf of Mexico, across and near the mouth of the Passes, and that an eddy current commences there and flows westward along the Louisiana coast."

At the head of the South Pass, complications existed in the conditions, which made it necessary to study the subject very carefully before commencing the works. The problem of how to deepen the inlet channel was far more difficult than any presented at the mouth of the Pass. When the natural conditions there existing are fully understood, it will appear that the artificial change in any of them must necessarily affect all the others. No problem had ever before been solved in river hydraulics in which there were such tremendous forces and so many variable elements.

To comprehend the necessity, commercially, for the work, the eye must sweep over the map of this country, and trace the one hundred thousand miles in the intricate network of this magnificent river and its tributaries, coursing their way to the Gulf through lands the most naturally fertile of any in the world. The territory enriched by it contains 768 000 000 acres of land; it would hold one hundred and fifty states as large as Massachusetts, and duplicate England twenty-four times over. It is the great arterial system of the Republic, and the mouth of the river is the natural gate-way to the world for its immense and varied productions. But all this inland wealth of agriculture and minerals was virtually land-locked by an obstruction at the mouth of the river, which, in these days of deep draught vessels of great tonnage, was turning rapidly to other ports and to other countries the commerce of the world, forcing also the construction of expensive and artificial lines of transportation over the mountains eastward. The special reasons for improving the mouth of the Mississippi were: First, the rapid development of the valley, and the impossibility of carrying its products by artificial lines of transportation. Second, the improvements that had been made in the inland navigation of the river and its tributaries, on which, for many years, large sums of money had been expended by the Government.

The following facts are given simply as illustrations of the necessity for improving the outlet of the river:

In February, 1859, a committee from the New Orleans Chamber of Commerce visited the mouth of the river, and reported that the value of merchandise delayed at the bar was—for exportation, $5 367 339;

and for importation, $2 000 000. In this estimate no account was taken of the value of the vessels, nor of any but the leading articles of produce, nor of the cargoes of ships which had cleared and were ready for sea, but whose commanders deemed it prudent to remain at the wharves at New Orleans until there was a prospect of getting over the bar without detention. One item of merchandise delayed at the bar was nearly 72 000 bales of cotton. Many of the vessels had been detained for weeks. A month later, there were thirty-five vessels inside the bar waiting to go out, three on the bars, and seventeen outside at anchor waiting to be towed in. From 1872 to 1877 inclusive, 417 vessels grounded and were detained at the mouth of the river, with a total detention of 12 467 hours. It was during this period that the Government made its most strenuous exertions to open a channel through the bars by means of dredge boats.

A narrow ditch not over 50 or 75 feet wide at the bottom, 18 feet deep, 5 miles long, was the only means by which the commerce of the Mississippi Valley could go out to the world. This channel, opened by artificial means, was filled up by sediment during the flood season of the year, or completely obliterated at times by a storm which would wash the sand into the channel and fill it up.

The underlying principles of the improvement, fully enunciated by Mr. Eads at the time, in Congressional documents, were substantially as follows :

The improvement of the mouth of the Mississippi by jetties consists in an artificial extension of the natural banks of the Pass, from the point where it commences to widen and disappear in the Gulf, to the crest of the bar, about 2½ miles distant. The Mississippi is simply a transporter of solid matter to the sea. This consists chiefly of sand and alluvion which is held in suspension by the mechanical effect of the current. At the Passes, after flowing for several miles through a deep channel, bearing onward without obstruction in its strong current, this sedimentary matter between narrow and parallel banks, the river widens out at the South Pass from about 700 feet to about 2 miles. Here, the shore currents are continually dropping the surplus load which their diminished velocity is unable to hold up, and thus the shores of the Pass are being constantly built up and narrowed in, and brought to the surface of the water, where, with reed grass, marine plants, etc., they are gradually converted into dry

land. The strong central current, however, is maintained intact by the reduced depth over which the stream passes, as it expands like a fish's tail out to the bar. The velocity of the stream being maintained by shoaling in depth as it expands in width, it is able to transport its entire load out beyond the bar, excepting only that which it has dropped on the submerged and incipient shores of the Pass. Although the current is strong out across the bar, it is soon checked because of its immense width and shallow depth, by which great friction in proportion to volume is produced. Hence, the load is deposited just outside the bar, and its constant outward growth is thus assured, while the growth of the shores of the Pass follows in due order. It is a mistake to suppose that the Gulf presents a barrier to the onward flow of the stream at the mouth of the Pass. On reflection, it must seem reasonable that a river should flow with less friction between walls of water than between walls of earth. It has, however, no longer a descent of a few inches to the mile, and hence must maintain its current in the Gulf simply by its momentum. Friction on its sides and bottom is the agent which finally brings it to rest; but, while its momentum lasts, the widening out into the sea, and the final obliteration of the river, will proceed very gradually.

If, from a point where the banks of the Pass are 700 feet asunder, and its depth 30 feet, we should artificially prolong them to the crest of the bar, still keeping them but 700 feet asunder, we should inevitably have 30 feet depth at the mouth of these jetties, and the great reduction of friction accomplished by narrowing the channel to 700 feet will enable the momentum of the stream to be kept up to a greatly increased distance beyond the bar, and hence the river will be able to carry to greater depths and into stronger Gulf currents that load which it is now only able to deposit just outside the bar.

The principles here enunciated, and others of perhaps equal importance which might be mentioned, but which there is no time here to dwell upon, already had been proven to be sound in a work constructed under almost similar conditions at the Sulina mouth of the Danube. It was a knowledge of this work, and of other important improvements by jetties in Europe, that made Gen. J. G. Barnard, M. Am. Soc. C. E., in distinction from the other United States Army Engineers, such an earnest advocate for their application at the mouth of the Mississippi. In his

minority report of the Board of Army Engineers, in 1874 (which Board decided in favor of the Fort St. Philip Canal, and against the jetties), he made a forcible and eloquent plea for the jetty system as against the Fort St. Philip Canal, closing with these memorable words:

"The advantages of an open river mouth are inestimable. The needs of a navigation so great as that which now exists, and which in the future of the great Mississippi Valley must be fifty-fold increased, demand it. It is said that 'the time has come' when the needs of commerce demand the canal; but I answer that the *time will come* when there will be the same cry for a navigation unimpeded by locks—an open river mouth—which we now hear for a canal."

The distinguished civil engineer, Sir Chas. A. Hartley, Chief Engineer of the European Commission of the Danube, ably advocated the jetty system at the mouth of the Mississippi, as being a much more favorable location than that at the Danube, where the depth was increased from 9 to 21½ feet. In his argument he states facts about the retardation of the bar advance at the Danube, caused by the construction of the jetties, in which there had been an experience of ten years after the completion of the jetties; he says:

"My conviction is that, by increasing the erosive powers of the current, relatively to the depositing action, the piers will have the effect, not of accelerating the growth of the accretions of the sea bottom, but of greatly retarding it. Practically, therefore, I consider that the element of bar advance may be discarded from the minds of the present generation."

The propositions enunciated by the Board of Army Engineers, and by the Chief of Engineers, on which they based their published prophecies of failure, were:

First.—That the jetties would be undermined at the sea ends;

Second.—That the foundation on which they would rest was unstable; and

Third.—That there would be a greatly accelerated advance of the bar after the jetties were constructed.

Three positive opinions were given in official reports by three prominent United States Engineers—one the then Chief of Engineers, another the present Chief of Engineers, and the third the officer in charge of the improvement of the Gulf ports—in reference to the rapid and accelerated growth seaward of the bar in consequence of jetties,

which would produce a depth of from 25 to 27 feet, if such could be constructed. These gentlemen respectively gave as the annual rate of advance, after the construction of jetties at the mouth of the South Pass, 670 feet, 2 240 feet, and (in the language of the third) "Jetties will have to be built further and further out, not annually, but steadily every day of each year, to keep pace with the advance of the river deposit into the Gulf, provided they are attempted."

The necessary extension of the jetties into the Gulf with these rates of bar advance would have been up to this date respectively three-quarters of a mile (to where there is now actually 160 feet depth of water), two and one-half miles, and well out towards Cuba.

Descriptions of the works have often been given, not only in the papers read before this Society, but in the current periodicals, and in the "History of the Jetties," the latter with full illustrations. It will be sufficient to state that the channel width, as it now exists between the works at the mouth of the Pass, is about 700 feet. The length of the East Jetty is about 2¼ miles, and the West Jetty 4 000 feet less, the sea ends being about opposite each other. The jetties are built of willow mattresses, whose dimensions were usually 2 feet thick, 100 feet long, and from 20 to 50 feet wide, sunk with rip-rap, and capped at the outer ends by concrete blocks. The jetties extend into 30 feet of water on the seaward slope of the bar.

At the heads of the Passes a variety of methods were employed, most of the dykes, however, being built of mattresses set on edge, with the object of checking only the flow of the current and inducing deposit. Concentration of the inflowing volume in its passage over the shoal was the great object in view, and the inlet channel was narrowed by the dykes to 800 feet. During the progress of the work here it became very evident that it would be necessary to bridle, guide and control the whole mighty torrent of the river, 8 000 feet wide, 30 feet deep, and with a velocity of 5 feet per second; for the contracting dams and dykes at the head of South Pass, while they deepened the channel into that pass, also tended to deepen the channel through the two larger passes, increasing their volume and depleting that of the South Pass. To hold the Passes at their normal size, sills or submerged dams were laid entirely across on the beds of the Southwest Pass and Pass à Loutre. The mattresses in these sills were generally 30 to 40 feet wide, 60 to 70 feet long, and 2 feet thick, so laid as to leave no opening

between them, but to make a continuous construction from the main banks of the river to the works at the head of the South Pass. The works of minor importance, such as closing bayous and similar work, need not be described here. A general plan was followed throughout, founded on the principle of concentration and utilization of the maximum normal volume of the Pass. The channel required at the jetties by the contract with the Government was 26 feet depth, 200 feet width, with a central depth of 30 feet.

Second.—Results.

From the moment of laying the first mattress at land's end to the present moment, there has been a constant development of the channel. At the end of the first year's work, although the jetties were simply walls of uncompressed willows, holding within the new channel only a portion of the volume of the Pass, yet important results were accomplished. Everywhere the principle was illustrated that with a bed composed of a yielding material, any obstruction, however small, will cause a deepening somewhere in its vicinity. Especially marked was the result of the works built in the fall and winter of 1875. The river rose in January, 1876, and the floods that had hitherto found a wide mouth through which to discharge their waters now struggled to reach the sea through a contracted outlet. Finding the bar like a dam in the channel, they attacked it with great force, the first result of which was, that wherever there were deposits of sand a rapid and decided deepening occurred. Over the whole two and one-third miles from the land's end to the Gulf a most irregular channel appeared, full of ridges, mounds, deep excavations, and suddenly appearing and disappearing shoals and channels; but after a time comparative uniformity in section and regularity in the course of the channel took the place of these variable conditions.

During the succeeding three years similar developments were traced. The pronounced irregularities in depths and alignment, due to the first strong efforts of the river to make an adequate channel to the sea, gradually disappeared; the channel became more navigable, the currents parallel with the jetties, and the steady, deep, quiet flow of the Pass above the jetties was more and more noticeable. During these four years of developing channel there were excavated by the accelerated current

7 607 151 cubic yards of material from the bottom and carried seaward. Since July, 1879, when the works were completed, the development has continued.

From Mr. C. Donovan, United States Assistant Civil Engineer, who has had charge of all surveys for the Government since 1876, the following facts have been obtained, taken from his charts of surveys of May 26th, 1884: The length of the 45-foot channel from East Point to the end of the jetties is 3 900 feet. The length of the 38-foot channel from East Point to the end of the jetties is 10 350 feet, or over 2 miles. The least depth through the jetties is 33 feet. The width of the 26-foot channel is 290 feet. Beyond the end of the jetties, between two old mud lumps, the least depth is 31.8 feet, and the least width of the 30-foot channel 70 feet. Compared with the survey of May 22d of last year, the 40 feet depth then existing through the jetties is found to have extended during the year 2 400 feet.

As to the permanence of the works, the test of nine years, during at least three of which the works were in an incomplete condition, attests the ability of dykes built of willow and brush mattresses to stand intact in a sea-way, and where capped and compressed by concrete blocks to be undisturbed by almost any wave force. They have withstood also the ravages of the *teredo*, the silt packed solidly among the willows preventing their inroads to any great extent. There has been no tendency to undermining at the sea ends of the jetties, though this was one of the prophesied results. The reason for this is, no doubt, that the frictional resistance of the jetties has slowed the currents near them, and thrown the deep channel and strong current near the centre. During the first two years after completion the more violent storms washed the sands over the jetties into the channel at times, causing a temporary shoaling, but since then lines of interior and inexpensively built jetties have prevented this action of the waves, the space between the main jetties and the interior jetties being quickly filled up by the deposits from river sediment and wave action.

The simple facts, that a deep channel exists at the mouth of the jetties; that in the track of the fluvial discharge, over a path at least 1 000 feet in width, the latest surveys show but slight shoaling; that the jetties since their completion in 1879 have not been advanced seaward one foot; that before they could be completed the accelerated shore current across the face of the bar increased the depths so

that the foundations, as planned and actually laid, are now from 150 to 300 feet beyond the present and completed jetty end,—these are most substantial and convincing proofs of the opinions advanced so earnestly ten years ago that the jetties would retard instead of accelerate the seaward growth of the bar. That in the course of many years there may be a necessity for an extension of the jetties it would be foolhardy to deny, for even under the improved conditions produced by the jetties, the 277 000 000 cubic yards of solid matter discharged from the mouths of the river will at last show a general advance along the whole line of the delta. The deposition of sediment now taking place on the wings of the jetties beyond the sea ends will be, however, if anything, an advantage in any future extensions, for it is slowly building up foundations for the work that it may then be necessary to build upon them. But for us and our posterity, it will only serve to perpetuate in the line of the river's discharge the deep channel it has maintained during the last six years. This result is partly due to the existence of a littoral current, the proofs of which, often alluded to, are abundant. The writer's own observation and experience convince him beyond any possibility of contradiction that there is a sufficient current across the face of the South Pass bar to account for many favorable results that may seem to some simply phenomena.

At the head of the Pass the dykes and dams have simply assisted Nature in her eternal river work of opening channels and building banks. Some of the works and all the outlying intermediate spaces, where formerly the waters flowed many feet in depth, are now covered with reeds and grasses well rooted in the firm ground. Through the channel between the river and the South Pass there now exists a wide, straight channel, the least depth being 35 feet, and the 30-foot channel 275 feet wide at its narrowest point, and it may be stated here that the least depth through the South Pass itself is now 30 feet. This branch of the subject would be unfairly dismissed without reference to the delicate and difficult engineering problem at the head of the Pass, so successfully solved. In this connection there may well be recalled the remark of that honored member of our Society, Col. W. Milnor Roberts, that the problem to be solved at the head of the Passes was the most difficult of any ever brought under his notice, with such mighty forces, yet so delicately adjusted, and in such perfect and sensitive equilibrium : "Still further,

when we contemplate the fact that these works are composed almost wholly of light willows, with a large portion of the mattresses standing on edge, simply as screens to check the current and cause deposit, they constitute a remarkable illustration of how completely the immense forces of Nature may sometimes be controlled by a wise use of the most inexpensive and unsubstantial materials, which Nature seemingly places within the reach of man for the very purpose. Here, by the gentlest influences, the mighty current is swayed and directed, completely obedient to his will. There is no instance, indeed, in the world, where such a vast volume of water is placed under such absolute and permanent control by the engineer, through methods so economic and simple, as those adopted at the head of the Passes of the Mississippi River."

The great and sole object of all these works, and those at the mouth of the Pass, was the benefit of commerce. What has been done? To say that vessels drawing from 25 to 26 feet of water pass out without delay is not enough. To say that even deeper draught vessels can do this is not enough, and it is not too much to say that the entrance to New Orleans from the sea is equal to that of any large port in the United States. The effect on the business of this city can best be briefly told by the former President of the Cotton Exchange, Gen. Cyrus W. Bussey, who stated in a letter written June 10th, 1884: "I am able to report that all that was predicted for the jetties has been realized, and more. Ever since their acceptance by the United States Government in 1879, there has been no complaint of delay at the mouth of the river, except in very rare cases, when vessels have been run out of the channel. At all times there has been a good, safe, practical channel for the largest vessels coming to any of the ports of the country. The influences of the jetties on the transportation routes of the country have been to cheapen rates to such an extent as to save to the producers a sum difficult to estimate. I am sure it would amount to ten millions each year on the cotton and grain transported, besides a large saving on the immense imports from foreign countries. New Orleans is exporting a larger proportion of the crop, and at much lower rates for freight, than ever before. This is in consequence of the constant presence in the harbor of New Orleans of the largest class of freight steamers seeking cargo. Ten thousand bales of cotton have gone out through the mouth of the river on a single ship. Before the jetties were constructed, the delays on the bar at Southwest Pass were so frequent that it was

extremely difficult to get a vessel to take more than 20 000 bushels of corn or wheat; but now, as you will see by the report of the grain inspector of New Orleans, which I inclose, 95 000 bushels is an ordinary cargo, in addition to which the vessel carries several thousand bales of cotton. A cargo of 144 000 bushels of grain has gone to sea on a single vessel. The wisdom of the construction of the jetties has been overwhelmingly demonstrated, and all that was predicated for them has been realized."

New Orleans, under the impetus of a new life, is taking rank among our most important ports and enterprising cities. The present project of a World's Fair never would have been undertaken had not the monsters of the world's marine been admitted through the now widely open gateway of commerce.

Third.—Lessons.

The principles of river hydraulics proven to be correct in the results thus briefly described, and the lessons taught by these ten years of harbor and river work, are not alone applicable to jetties at the mouth of the Mississippi River. They have an important bearing upon all harbor and river improvements along our own coasts and rivers and throughout the world. They disclose most certainly the erroneous views that have been held and defective plans that have been pursued, and it is the special useful object of this *résumé* to apply the lessons to all improvements that are in their conditions and objects in any way similar to those at the mouth of the Mississippi River.

First.—Dispersion shoals—concentration deepens. The "outlet" theory is disproved. It has been condemned by the highest authority—by the Mississippi River Commission, who have surveyed, examined, experimented upon and studied the subject during the last four years. Several Congressional delegations, prejudiced at first in favor of it, after a patient examination, reported in favor of the concentration, or rather conservation plan; but no facts from actual results of works constructed more clearly prove than those we have given, or could give, that to carry the floods safely to the Gulf, and to utilize them to deepen channels for our inland commerce, we must hold them within bounds by adequate and properly constructed dykes, jetties or levees, and thus lead this mighty force placed at our disposal to excavate for us, down into the bed of its own making, deep channels for our vessels and steamboats, constantly increasing in size and draught, to carry the accumu-

lating products of the rapidly developing valleys. This lesson is one of paramount importance in river and harbor improvements.

Second.—The flood volume of the river, and the full volume of the tides, are the powers which the engineer should call to his aid. Therefore, jetties, to be of the greatest effect, should be brought above the surface of the water at flood tide, outlets should not be left through them, and the jetties should be placed as near each other as the volume and current passing in and out show to be necessary for making a channel of adequate depth and width in the shortest possible time. The neglect of these lessons, or rather the plans and constructions carried forward on opposite principles, have at Galveston, Texas, and Charleston, S. C., resulted in complete failure. At the former bar, the groundless fear of a bar advance compelled the location of jetties 2¼ miles apart, where, too, the tides are not over 14 inches, and are the only force that can be brought to bear upon the bar. Neglecting another lesson, the jetties were submerged, or drowned, so that the strongest force was dissipated by diffusion and the excavating force of the currents lost by lateral waste; but, further, to effectually destroy the scouring force of the current, lateral outlets were left near the land, ostensibly to let the tides into the bay, but through which at ebb tide they sought to find the lower level of the Gulf, instead of taking the five-mile course through the laid-out jetty channel over the frictional sands of the bar. Under these mistaken views and plans, the results have been as follows:

In 1874 (the same year in which this record of the Mississippi River jetty work commences), the depth across the Galveston bar was 12 feet. That winter a violent storm increased the depth nine-tenths of a foot. The works were commenced that same year, and continued under Government appropriations, and by Government engineers, to the present time—ten years of work and results. In 1880 the Army Engineer in charge reported a depth of 12¼ feet. In 1884 the depth reported was 13 feet. One and a half million dollars have been expended upon this work. It is safe to say that had the correct principles been applied ten years ago at Galveston harbor, as at the mouth of the Mississippi, that important port would long ere this have been happy in a channel 30 feet deep. At Charleston, similar [plans, prosecuted through nearly the same length of time, produced the same, or even less results; the chart showing the depth over the bar to be 2 feet less now than when the works were commenced.

Third.—It is necessary to raise jetties high enough above the surface of the water to prevent the sands from washing over the works into the channel by the force of the storm waves. Experience shows this to be absolutely necessary to preserve the channel, or an interior line of works may be so constructed that the intervening space may become filled and packed by the sand, solidifying the works and preventing leakage.

Fourth.—The concentrated volume will, with its increased slope and accelerated current, obtain what it will maintain, and, conversely, it may be stated that it will not maintain what it cannot obtain. Volume, slope, current and friction of bed are all so intimately connected and interdependent, and it may be said sympathetic, that when one is disturbed all the other elements at once set themselves at work to restore the normal and healthy condition of the disturbed element. In an alluvial bed this natural equilibrium is perfect, even the velocity curves, both horizontal and vertical, and the curve of the cross section of the river bed, assuming a beautiful uniformity and similarity. We can, therefore, change only the form of the channel, unless we can permanently increase its volume. The uselessness and the perpetual labor imposed on man to attempt to deepen without contracting the flow, is seen by years of expensive work by powerful dredge boats at the bar of the South-West Pass, striving against the retributive laws of Nature to keep open a channel 5 miles long. The patience exhibited by the Government and its employees was heroic. How often has the writer, in the early months of the first year's work at South Pass, watched from some observation tower, with a telescope, the black column of smoke rising all the day, and all the days, miles away, from out the great waste of reeds and waters; the tall masts of sailing vessels and steamers some distance to the right and left showed the waiting fleet at anchor, hoping to see the monster dredge move out of the only ditch through which they could, one by one, each in his turn, go up to the port, or out to the sea, dragged mercilessly through it by the tugging harpies who were always watching for their prey. This ditch would invariably fill up during a storm by the sand washed in by the waves, or the rapidly dropping sediment of the current, slackened by the frictional resistance of the great bar, would fill it with mud. Like the Augean stables, it needed a Hercules to turn a current through it, and carry the objectionable detritus into the great depths of the Gulf beyond.

At the head of the Pass, during the construction of the works, and be-

fore the necessary construction was accomplished, an attempt was made by a sanguine man, at his own instance, to wash out a channel by artificial means. Every opportunity was given him, and a handsome bonus offered if he should accomplish the deepening desired. He constructed a machine for the purpose, at considerable expense, the general plan of which consisted in directing the current by a deflecting board against the sand of the river bed, thus washing out a trough and permitting the boat to move down stream, carrying this trough before it, and as it were shaving off the crest of the bar about 6 inches each time the machine drifted over it. A deepening of about 2 feet was accomplished, and the removal of about 5 000 cubic yards of sand, but the causes that produced and maintained the shoal restored the lesser but normal depth; the channel that had been deepened by this artificial means shoaled again to the exact depth it had before the dredging commenced, and the project was abandoned.

Fifth.—The lessons from the works and their results at the head of the Passes are very instructive, and have for several years proved that willows and brush, used for simply slacking the current, will cause deposit and improve the contiguous channels. This inexpensive material, generally so abundant along our alluvial basins, was combined into different forms, simple, yet novel, and the cheapness with which the work was performed, and the effectiveness of its application, were so surprising that this system of controlling silt-bearing currents has been adopted by the Army Engineers throughout the Mississippi Valley, and it may be copied advantageously by the older nations of Europe, where the same materials have long been used for similar purposes, but with much less economy and benefit.

Sixth.—In the construction of jetties across river or harbor bars, they must be pushed forward rapidly to completion. Lessons from European jetties taught this for our benefit, and every exertion was made to complete the works promptly. The lesson of the Rhone was before us, where, together with other lesser causes for the bar moving seaward, was the fact that the jetties were never carried nearer than one mile to the crest of the bar. Even with all the speed with which the works were built at the South Pass, the effect of a partial contraction only was seen in the fall of 1875, especially upon the crest of the bar, where, in October, the depth was reduced about 18 inches.

Seventh.—A deep channel, 26 to 30 feet deep at the ends of the

jetties, in the Gulf of Mexico, is below the depositing action of the waves. The waves are seldom more than 15 feet in height, measured from the trough to the crest. Sand is deposited and moved along the shore in depths less than 25 feet. Therefore, it is of vital importance to secure as quickly as possible an outlet channel of greater depth than this, to ensure it against the deleterious effect of moving sands.

Eighth.—The lesson of the greatest practical importance is that properly designed jetties, with a deep channel and strong outflowing current, will not only not accelerate the advance of bars, but will greatly retard their growth.

This work, and the principles that underlie it, the results and the lessons, the obstacles natural and personal, with which it had to contend, have become matters of history. You have followed it through all its phases; you have appreciated the conditions, the problems, and the obstacles; you will share the just pride in the successful issue of this whole matter. We have the greatest satisfaction in having gained a signal victory over immense natural forces full of complicated conditions. It is a part of our profession to study and understand the laws governing the flow of water; you feel the fascination of the problem that was studied and mastered at the mouth of the Mississippi River; you rejoice with us because we have controlled and guided, by attention to its own laws, one of the mightiest forces of Nature, and have made it a willing servant at our behest to minister to the interests of the great valley that to-day goes out untrammeled to the world.

When the plans for improving the mouth of the Mississippi River were before Congress in 1874, they were submitted to several of the Civil Engineers of the country for examination. Their opinions are now on record in the archives of Congress. These gentlemen, Messrs. W. Milnor Roberts, J. H. Wilson, C. Shaler Smith, O. Chanute, G. W. R. Bayley, and Henry Flad, are entitled in a *résumé* of this great work to a share in its success for having boldly, and in the face of opposite and publicly expressed views, given their adherence to the plans proposed.

Finally, a lesson may be drawn from this matter concerning the proper mode of carrying on public engineering work. That lesson is, as it appears to the writer, that the Government should summon to its aid the best engineering talent within its reach, and should not give the general or exclusive charge of public improvements into the hands of engineers educated to conduct works of a totally different character.

Let the doors be thrown open freely to all engineers fitted by education and experience for the service required.

In connection with this lesson, it is a suggestive fact that no other civilized country puts its river and harbor improvements into the hands of other than Civil Engineers.

The appreciation in which the results of the Mississippi jetties are held by the commercial world is satisfactorily shown by the award made by the British "Society for the Encouragement of Arts, Manufactures and Science," of the Albert Medal, which was presented by the Prince of Wales to the designer of the works, who is entitled in the justly complimentary resolution of award: "Captain James Buchanan Eads, the dis-"tinguished American engineer, whose works have been of such great "service in improving the water communications of North America, and "have thereby rendered valuable aid to the commerce of the world."

AMERICAN SOCIETY OF CIVIL ENGINEERS.

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TRANSACTIONS.

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CCXCI.

(Vol. XIII.—October, 1884.)

LEVEE THEORY TESTED BY FACTS.

By ROBERT E. MCMATH, M. Am. Soc. C. E.

READ OCTOBER 15TH, 1884.

In an unofficial, but authoritative way, the following question has been stated by the Mississippi River Commission, and a majority of that body sustain the affirmative:

"Is it in accord with sound principles of engineering, and will it be "in like manner conducive to the improvement of the river, to confine "the flood volume within the channel by artificial additions to its "natural banks?"

To this question an emphatic denial is given by at least one member of the Commission in minority reports, and thereby open discussion is practically invited. Such discussion should be of interest to engineers, for aside from the immediate application, principles of physics are involved which are of great importance, if true, and very dangerous if false. Convinced that the proposition is a great error, I take the position that denial should go further than negation, and should furnish the proof, now at hand:

1st. That such confinement of flood volume will not be conducive to

the improvement of the river, either in respect to navigability or as a channel to discharge the drainage of a continent.

2d. That all facts of observation and experience, with emphasis on *all*, establish the truth of a contrasted proposition, viz.:

Engineering effort, so far as it may affect volume, should be in the direction of equalization, that is, to reduce the ratio between flood and low stage volume, by reducing the former and increasing the latter by every possible means. Where great variations are unavoidable, as is the case in the Mississippi, the line of effort should be to render the changes from small to great volume, and the reverse, as unfrequent and gradual as possible.

The question, as between concentration of flood volume and equalization, turns upon the apprehension of and mode of accounting for two supreme facts:

1st. The bars which obstruct navigation in the Mississippi, below the Missouri, are higher after a season of high water than at the close of a period of low water; that is, high stages bring increased obstruction to navigation.

2d. The discharge for a given height on the gauge is materially greater immediately after a low stage period than immediately after a high stage; and if there be a succession of floods, the discharge of each succeeding one will, for a given height on the gauge, be less than for the preceding. That is, "The coming flood brings with it an "impediment to its own discharge, and the impediment outlasts the "flood."

Two modes of accounting for these facts have been proposed. One, that the first-named fact is due to the effect of width variation upon sectional area as the river rises and falls, by which the areas at wide and shoal sections are smaller at low stages and larger at high than at related narrower and deeper sections. As a consequence of these changes of relative area, wide places become subject to deposit at high, and to scour at low stages, a reverse action occurring at the narrow sections. This alternate action is the occasion of by far the greater part of silt movement. A demonstration that this must be was given by the writer in a paper printed by this Society in 1880 as No. CCVI, and more fully in Appendix K to Report of Mississippi River Commission for 1881. The following table shows the reality and importance of the changes:

TABLE OF WIDTHS, AREAS, VELOCITIES, DEPTHS AND SLOPES AT CRAIGHEAD SECTION, MISSISSIPPI RIVER.

No. of Section.	Distance between.	Low Stage, Nov. 13th, 1879, 0'.0.					High Stage, Jan. 3d, 1880, + 26'.6.					Change of Channel Depth.
		Width.	Area.	Mean Vel.	Chan'l Depth.	Fall in 1 000'	Width.	Area.	Mean Vel.	Chan'l Depth.	Fall in 1 000'	
Bullerton. 6	1 040	6 535	42 040	1.88	11.0	0.183	8 565	234 190	4.08	32.0	0.058	— 5'.6
Bullerton. 9	1 660	6 250	37 770	2.09	14.0	0.386	8 680	243 000	3.93	37.0	0.078	— 3'.6
—	1 200	6 010	39 620	2.00	17.0	0.381	8 840	260 000	3.67	36.0	0.091	— 7'.6
3	1 880	5 375	52 280	1.51	26.0	0.240	8 150	249 820	4.00	41.0	0.004	—11'.6
5	2 260	4 250	36 080	2.19	28.0	0.239	7 610	229 030	4.17	52.0	0.053	— 2'.6
6	1 300	3 550	40 595	1.94	33.0	0.277	7 610	231 000	4.13	54.0	0.077	— 5'.6
7	1 300	4 575	41 930	1.90	31.0	0.253	7 600	220 620	4.33	55.0	0.053	— 2'.6
8	1 500	4 450	37 800	2.09	21.0	0.273	7 930	244 410	3.91	47.0	0.086	— 0'.6
9	1 180	4 810	34 020	2.32	20.0	0.381	8 010	227 230	4.17	45.0	0.068	— 1'.6
10	1 200	3 190	40 930	1.93	23.0	0.250	7 250	203 970	4.68	49.0	0.133	— 0'.6
11	1 420	2 267	30 220	2.61	25.0	0.225	6 170	175 740	5.43	55.0	0.183	+ 3'.4
12	1 510	3 210	41 650	2.42	26 0	0.159	5 490	167 770	5.69	59.0	0.146	+ 6'.4
13	1 480	3 467	46 680	1.90	18.0	0.202	6 530	175 850	5.43	54.0	0.081	+ 9'.4
14	1 500	3 183	40 200	1.70	28.0	0.100	7 340	175 500	5.43	57.0	0.133	+ 2'.4
15	1 400	2 958	48 740	1.97	29.0	0.121	6 570	176 300	5.41	57.0	0.121	+ 1'.4
16	1 500	2 625	48 110	1.62	31.0	0.080	5 990	168 650	5.60	56.0	0.146	— 1'.6
17	1 400	2 358	49 325	1.64	34.0	0.050	5 300	170 200	5.61	62.0	0.136	+ 1'.4
18	1 460	2 192	51 935	1.60	30.0	0.069	4 840	159 350	5.99	64.0	0.185	+ 7'.4
19	1 480	2 517	56 660	1.52	31.0	0.007	4 920	154 600	6.17	62.0	0.149	+ 4'.4
20	1 600	2 317	59 210	1.40	27.0	0.006	5 600	199 850	4.78	59.0	.....	+ 5'.4
21	1 500	3 983	51 690	1.33	24.0	0.007	6 180	217 650	4.39	52.0	.....	+ 1'.4
22	1 800	5 200	41 530	1.53	22.0	0.017	6 450	229 000	4.08	49.0	.....	+ 0'.4
23	2 700	3 600	41 530	1.90	54.0	0.033	5 480	196 830	5.00	74.0	.....	— 6'.6
24	2 700	2 125	45 870	1.72	58.0	.....	3 760	143 510	6.65	81.0	.....	— 3'.6

The rise and fall of the shoals under the first fact affect the hydraulic conditions of the river and so produce the second fact, diminished capacity for discharge, beginning when the bars commence to rise and following them in direct relation. The relation of bar or weir height to velocity and discharge was discussed in No. CCXXXIX of papers before the Society, printed in 1882.

The other mode of accounting for the facts is advanced by the Commission in effect, but not in formulated statement. They claim that when the river begins to overflow its banks a remarkable loss of velocity in the stream occurs. That is, the velocity of the current, which normally increases at a regular rate as the river rises, suddenly loses that rate of increase at the level of overflow, and may show actual loss as the river rises and spreads over the bottoms.

Next it is assumed that the stream is loaded to its full carrying capacity with sediment, and therefore is exceedingly sensitive to change of velocity. To quote from one member of the Commission (Judge Robt. S. Taylor in *North American Review*, March, 1884, page 290): "The least halt in the great procession of particles precipitates part of "its constituent membership to the bottom. There they create an "obstruction which prolongs the halt; the prolonged halt increases "the obstruction, and so on, each condition reacting on the other. "The result is decreased velocity and increased rise in the stream."

To a disinterested onlooker it must appear strange that the Commission should make much of the loss of velocity occurring at top of flood, which in no case exceeds 20 per cent., as a cause of deposit, and overlook the variations of velocity due to difference of sectional area, which often amount to 50 per cent. and more in a few miles distance. These variations are just as important before as after overflow, as the table just given clearly shows.

To put the two modes of accounting for the facts clearly before the eye and mind, diagrams 1 and 2, Plate XLIV, will be used.

By my explanation, the rise of bar during flood from A to A', Fig. 1, Plate XLIV, is determined by relative widths. $A\ B$ and $A'\ B'$ are the origin of velocity before and after flood. A continuous series of observations during a complete cycle of rise and fall will approximate an enclosed figure as the velocity curve. The stream under the changed conditions must rise from C to C', in order to discharge an equal volume.

The Commission's explanation, reduced to ultimate terms, is, that if a

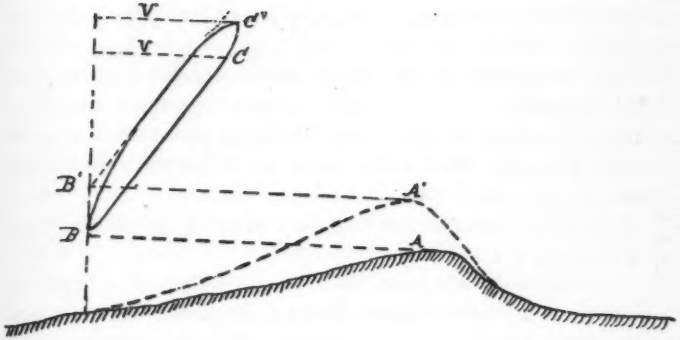

Fig. 1.

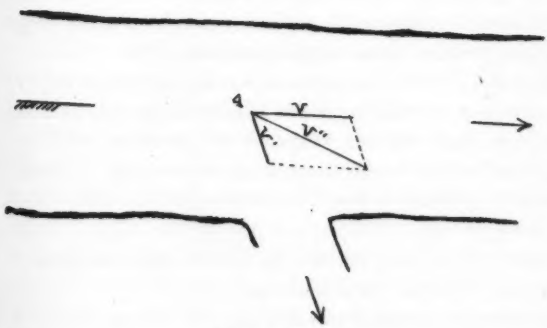

Fig. 2.

PLATE XLIV.

particle of water at A, Fig. 2, Plate XLIV, under the influence of a fall in the direction of the channel capable of producing the velocity V, is exposed to the attraction of a new force capable of producing a velocity V' toward and over the bank, a loss of previous velocity will ensue and a corresponding decrease of transporting power. To quote their latest utterance: "The loss of volume through high water outlets causes both "a diminution of velocity and a deflection of the thread of movement of "the stream towards the outlet, accompanied by loss of the power nec- "essary to transport the material with which it is loaded. The excess of "load is dropped in the bed, decreasing the section below the outlet." (Report for 1883, page 18.)

The fallacy of their argument is made apparent by completing the parallelogram, $V'' > V$.

They are correct as to facts, but wrong in theory. The *accelerated* current above the outlet, which extends for miles, provokes local scour and brings to the outlet material which cannot go out, and this material passing into the *normal*, but comparatively slack, current below the outlet, is dropped and decreases the section. A diffused overflow exerts no such influence and produces no such result.

Another idea, held by some, is that the quantity of sediment borne at different depths increases in some ratio to depth below surface, hence that the escape of the surface and less burdened water by overflow brings about an enormous decrease of silt-carrying capacity.

Both ideas make overflow the occasion of deposit within the bed through a diminution of velocity, which must be as general as is the overflow; hence the deposit should be general also, bars and pools sharing alike; or, if there be difference, the deep pools should receive the greater deposit, for overflow is largely at the bends. It is well known that deposit on bars is often 10 and more feet in depth. Suppose such a deposit general in a river nearly a mile wide, and the source of the material to make it must be sought for and shown.

From the foregoing statements it appears that the two modes of accounting for the facts are widely apart, reversing the relation between antecedent and consequent; therefore, if one even approximates the truth, the other must be wholly false.

By the mode first stated the process of filling on bars should begin at a mean stage, or when the rise passes a certain limit, which is variable with season and locality, but found at a lower level where the differences

of width are great than where they are small. By the other mode that beginning must be at the stage of overflow. Which is true, is therefore readily determinable by observation of the time and stage when such fill begins. Such observations, made in an unscientific way, have established among boatmen the maxim that even a moderate rise will injure—"flatten out"—the channel. Experience has also taught the working engineers, who have had actual contact with the facts, that the change of bar height occurs, in numerous cases, when the rise does not reach overflow or even near it. Consequently, the presumption is so strong against the second mode that the burden of proof rests upon its adherents.

The Mississippi River Commission, with means in its hands for, and professedly engaged in physical investigations, has not, in the four years of its existence, succeeded in finding any evidence whatever of the possibility of the theory which is fundamental to the scheme of improvement proposed.

Although the Commission has not sought a direct test of its theory, every line of investigation, whatever the immediate object may be, cannot fail to bring out evidence bearing upon the subject. These side lights, so far as they have been made available for public discussion, I propose to use in proof, that deterioration of channel in navigable depth and hydraulic capacity is not caused by overflow, and is not necessarily, or even ordinarily, associated with it in time or place; therefore, it will not be conducive to the improvement of the river to confine its flood waters within the channel by artificial additions to its natural banks.

The first class of observations I will use is discharge observations. I will take from the mass of concurrent testimony three cases that have been publicly cited as proof of the Commission's view, and of which it has been semi-officially said: "It is obvious that in each of "these cases there was a choke of some kind in the river. There was "no visible obstruction in any of them to create it. It was coincident "with general overflow and did not appear at any other stage (?). The "inference from these circumstances alone, that it was in some way "caused by the overflow, is by no means illogical." With the facts so cited I will quote others in the immediate series, so as to present the several cases in the light of their actual association with other and more important phenomena than overflow.

The first case was at Grafton, Ill., during the rise of April and May, 1881, covered in the table below, in which the last column shows the change in sectional area due to fills and scours:

Date.	Gauge.	Width.	Sectional Area.	Mean Velocity.	Discharge.	Area Below Datum.
			Sq. ft.		Cu. ft.	Sq. ft.
April 20, 1881	29′.70	2 416′	64 463	4′.297	277 015	77 263
" 21, "	29′.88	"	63 525	4′.417	280 606	75 891
" 22, "	30′.29	"	63 657	4′.299	273 632	75 033
" 23, "	30′.83		63 800	4′.410	281 349	73 872
" *25, "	32′.17		67 545	4′.594	310 309	74 380
" 27, "	33′.19		73 620	4′.584	337 486	77 991
" 28, "	33′.48		73 815	4′.412	325 638	77 486
" 29, "	33′.68		73 920	4′.471	330 482	77 108
May 3, "	34′.02		73 435	4′.237	311 132	75 802
" 4, "	34′.13		73 725	4′.005	295 285	75 826
" 5, "	34′.22		74 010	3′.937	291 365	75 894
" *6, "	34′.16		73 695	3′.859	284 406	75 725
" 7, "	33′.79		72 832	3′.762	274 014	75 757
" 9, "	31′.94		68 192	4′.214	287 378	75 587
" 10, "	30′.86		66 698	4′.316	287 889	76 701
" 11, "	29′.96		64 485	4′.154	267 874	76 662

There was an overflow and slackening of current, but the velocity was recovered before the river returned within its banks. The explanation is very simple. The observation station was about 20 miles above the junction of the Missouri, and just below that of the Illinois with the Mississippi. The remarkable loss of velocity began April 22d, reached its maximum May 5th, and was wholly recovered from by May 10th. The Missouri River, at St. Charles, Mo., about 30 miles above the mouth, began to rise rapidly April 22d, reached a maximum May 5th, and then fell rapidly until May 11th. (See diagram of St. Charles gauge, Plate 4, Appendix H, to Commission's Report for 1881.) The Upper Mississippi and Illinois did not materially share in the rise, as is evidenced by the discharge column. The Grafton case, therefore, was no more than simple backed water. The observations marked by * in the table have been cited as proof of velocity lost by overflow. Change of section, as shown in the last column, was comparatively small and of no special significance.

Similarly, at Hay's Landing, Mississippi, the observations of two dates have been cited:

Date.	Stage.	Width.	Sectional Area.	Mean Velocity.	Discharge.	Datum Area.
			Sq. Ft.		Cu. Ft.	Sq. Ft.
Mar. 20, 1882.	38′.59	2 820′	172 105	5′.444	936 954	170 515
June 1, "	34′.15	2 707′	167 397	6′.265	1 048 750	178 244

and said to show gain of velocity as the river came within its banks after overflow.

I will take other observations at stages very near 34′.15, before as well as after overflow, and ask: How do the proposers of the overflow theory account for the fact that velocity and discharge at 34′.28 stage on January 21st, before overflow, was so much greater than at nearly like stages, April 26th, May 20th and 24th, and less than at 34′.15 stage of June 1st, all being alike after overflow?

Date.	Gauge.	Width.	Sectional Area.	Mean Velocity.	Discharge.	Datum Area.
			Sq. Ft.		Cu. Ft.	Sq. Ft.
Jan. 21, 1882.	34′.28	2 710′	161 534	6′.056	978 300	171 788
Mar. 20, " *	38′.59	2 820′	172 105	5′.444	936 954	170 513
Apl. 26, "	34′.15	2 699′	159 935	5′.358	856 940	170 788
May 20, "	34′.09	2 705′	162 672	5′.553	903 247	173 669
" 24, "	34′.20	2 707′	164 777	5′.555	915 381	175 489
June 1, " *	34′.15	2 707′	167 397	6′.265	1 048 750	178 244

I explain it as the result of backed water, and nothing else, during the rush of water from the Yazoo basin, which is partly measured by the difference in measured discharges at Hay's Landing and at Red River Landing, shown below:

Date.	Discharge at Red River Landing.	Discharge at Hay's Landing.	Difference.	
	Cu. Ft.	Cu. Ft.	Cu. Ft.	
Jan. 21, 1882.	1 050 024	978 300	71 724	These differences are a fair indication of the outflow from the Yazoo basin, but less in amount by the overflow into the Tensas basin.
Mar. 20, "	1 407 755	936 954	470 801	
Apl. 26, "	1 317 374	856 940	460 434	
May 20, "	1 175 341	903 247	272 094	
" 24, "	1 146 364	915 381	230 983	
June 1, "	1 137 809	1 048 750	89 059	

The evidence of discharge differences is corroborated by the gauge records, unpublished, at Hay's Landing and Lake Providence, 11 miles above, which show a flat slope between the two places on the dates when current was slow, and a steep slope June 1st. At the earlier dates the outflow from the Yazoo basin acted just like a flood from a great

tributary in backing the water for miles above its entrance. The Yazoo water began to reach the Mississippi a few miles below Hay's Landing, breaking through the levees from the rear into the Mississippi, and then out of the Mississippi into the Tensas basin through the Louisiana levees.

A third case is at Clayton, Iowa, and is a test, for it is clear of the suspicion of backed water. The locality is a few miles below the junction of the Wisconsin. The table, page 342, is extended to cover the rise from and return to a mean stage in May, and also the rise in October, in which the essential phenomena were repeated. The October observations have been cited in evidence that loss of velocity is caused by overflow, which, at the locality, becomes general at 14′ stage; but the similar loss in May, occurring at a lower stage in a rise which did not reach 14′, was overlooked.

The Clayton observations in May and October, taken together, therefore, furnish a complete refutation of the overflow theory. The asserted effect, loss of velocity, appeared when the assigned cause, overflow, was wanting. A similar case of loss in velocity and discharge, though stage increased, without overflow, is found in the Carollton observations of 1880, at a stage between 10 and 12 feet, and so in numerous cases which it would be burdensome to specify.

The overflow theory had its origin in a hasty interpretation of certain facts reported as attending a flood in the Missouri River in 1881; indeed, the same flood that caused the backwater at Grafton, and there furnished the delusive argument for the theory which has been refuted above.

The original statement concerning this Missouri flood, in Report of Commissioners for 1881, page 135, shows that when passing Sioux City the flood carried no sediment, that it was not augmented by floods from tributaries below that point, that nevertheless it became exceedingly muddy, filled the ordinary bed in places and made extensive deposits on the overflowed bottoms. "From Omaha, St. Joseph, Kansas City and "Glasgow, reports were received that after the river got out of its banks "the rate of rise increased, while the current was so materially slackened "in the course of a few hours that skiffs could row about with ease, "although before the river left its banks and after it returned to them "the current was so strong that even steamboats were unable to stem "it." Summing up a discussion of these reported facts, a Committee report says: "Hence, if the flood had been restrained by levees where

Date.	Gauge.	Width.	Sectional Area.	Mean Velocity.	Discharge.	Datum Area.	
			Sq. Ft.		Cu. Ft.	Sq. Ft.	
May 2, 1881....	8'.26	1 470	27 667	2'.725	75 393	42 158	
" 3, "	9'.10	1 471	29 471	3'.328	98 080	42 727	
" 5, "	12'.21	1 473	33 836	4'.007	135 580	42 499	Rise of 1.5 and loss of velocity, but no overflow.
" 7, "	13'.73	1 483	35 895	4'.001	143 626	42 304	
" 10, "	13'.51	1 483	35 279	3'.893	137 342	42 014	
" 11, "	13'.08	1 483	35 350	3'.814	134 826	42 723	
" 16, " ...	11'.07	1 478	32 332	3'.529	114 066	42 672	
" 17, "	10'.87	1 478	31 759	3'.526	111 983	42 405	
" 18, "	10'.68	1 478	31 486	3'.450	108 628	42 397	
" 19, "	10'.54	1 478	31 372	3'.414	107 104	42 490	
" 20, "	10'.40	1 478	31 416	3' 420	107 443	42 741	
" 21, "	10'.30	1 477	31 046	3'.378	104 875	42 519	
" 23, "	10'.14	1 477	30 483	3'.208	97 790	42 192	
" 24, "	9'.96	1 476	30 474	3'.203	97 609	42 449	
" 25, "	9'.82	1 476	30 087	3' 197	96 300	42 268	
" 26, "	9'.58	1 475	29 834	3'.162	94 335	42 369	
" 27, "	9' 40	1 475	29 586	3'.100	91 715	42 386	
" 28, "	9'.15	1 474	29 665	3'.072	91 130	42 834	
" 30, "	8'.76	1 473	28 670	2'.953	84 658	42 414	
Sept.15, 1881....	7'.58	1 471	28 011	2'.842	79 606	43 482	
" 18, "	9'.84	1 478	31 944	3'.439	109 855	44 081	
" 20, " ..	11'.22	1 482	34 003	3'.665	124 622	44 098	
" 21, "	11' 65	1 487	34 294	3'.731	127 950	43 740	
" 22, "	12'.00	1 488	35 297	3'.778	133 352	44 222	
" 23, "	12'.22	"	35 790	3'.738	133 782	44 388	
" 24, "	12'.23	"	35 517	3'.783	134 360	44 100	
" 26, "	12' 15	"	35 402	3'.658	129 502	44 105	
" 27, "	12'.08	"	35 552	3'.648	129 694	44 358	
" 28, "	12'.02	"	35 227	3' 640	128 227	44 123	
" 29, "	11'.92	"	35 094	3'.637	127 638	44 139	
" 30, "	12'.26	"	35 666	3'.770	134 462	44 205	
Oct. 1, 1881....	12'.40	"	35 807	3'.678	131 699	44 138	
" 3, "	13'.00	"	36 608	3'.960	144 968	44 047	
" 4, "	13'.68		37 620	4'.042	152 050	44 047	
" 7, "	15'.30		40 181	4'.095	164 540	44 198	
" 8, "	16' 20		41 272	4'.211	173 796	43 950	
" 10, "	17'.56		44 053	4'.066	179 119	44 707	
" 12, "	17'.25		43 833	4'.033	176 778	44 948	
" 13, "	16'.93		43 111	4'.050	174 600	44 702	
" 16, "	16'.44		42 319	3'.989	168 812	44 639	
" 18, "	17'.36		43 516	3'.979	173 150	44 467	
" 19, "	17'.63		43 973	3'.965	174 355	44 525	
" 21, "	17'.98		44 123	4'.035	178 034	44 153	
" 22, "	17'.90		44 159	4'.039	178 356	44 308	
" 24, "	17'.62		43 815	3'.925	171 974	44 381	Rise of 4.3 without any increase of velocity; general overflow.

"necessary, and, still better, if the high water section had been reduced "to any approximately uniform and suitable width, the water surface "would nowhere have surpassed, and would generally have fallen much "below, the level of the present banks." (Report for 1881, page 137.)

Accepting the facts as stated, a few simple considerations will overthrow the theory and condemn the remedy proposed:

1. How did the river, originally clear, and not receiving floods from tributaries, obtain the material for the enormous deposits noted? Obviously by scouring its own bed and banks in some places and depositing the material so obtained at others.

2. Did this scour take place when the river was still within its banks and the current very swift, or after the river got out of its banks, when it is said the current became slack? Certainly when the current was swift.

3. Did the scoured material continue in suspension until the river had gotten out of its banks, and then settled in the slackened current in a nearly uniform sheet everywhere? Or did it drop in reaches of excessive width, before as well as after overflow, as the water conveying it reached such places in its course, forming high bars which, acting as dams, obstructed the flow and sent the river out of its banks?

The statement is distinctly made that deposits 6 to 12 feet in depth were observed at sheltered places in the bed after the flood had passed, and from 4 to 6 feet deep on the banks. Can any one believe that such quantities of sand could have been held in suspension to await the hour of overflow?

Bring in the principle of alternating localities of scour and deposit, determined by relative widths, and how simply all the phenomena are explained. The built-up bars impeded the flood, slackened the current and exaggerated the overflow—antecedent and consequent, in an obviously natural order. The attempt to make these facts support a theory favorable to levees reversed the relation of cause and effect, and led to the statement, already quoted, to the effect, that if the natural banks had been raised artificially their original height would have been more than sufficient to hold the flood!

The theory upon which levee construction, as a means of improving the Mississippi, is proposed, in all its parts and particulars, is an inversion of the relation of cause and effect, and cannot be followed in any direction to a logical or experimental conclusion without meeting Nature's veto,

leading to direct absurdity or to practical failure, perhaps attended by disaster. I have sufficiently shown the falsity of that form of the theory which undertakes to find in overflow a cause of slackened current, and thereby of obstructed channel, by a review of the very facts cited in its support.

The contrasted theory is supported by these same facts and by all. In every series of observations, wherever taken, a tendency for the velocity and discharge curves, traced by connecting successive observations, to form a loop backward, at the top of a flood or moderate rise alike, is very noticeable. The looping becomes very conspicuous wherever the stream is subject to change of bed and bank, and the water flood is accompanied by a movement of silt. (See diagrams 3, 4 and 5, Plate XLV, for one of many samples which might be given.) The plotted positions are the mean of observations, taken in groups of five consecutive dates. (Report for 1883, pages 470, 471.) Also in streams whose bars "cut out" a converse looping forward becomes conspicuous at low stages. Beyond possibility of question, this looping forward is due to the cutting out of the bars or lowering the crests of submerged weirs, by which the gauge reading decreases, and area also, without a corresponding decrease of discharge and velocity, and this establishes a very strong presumption that the looping in the contrary direction at the other extreme of stage is due to filling bars or rise of submerged weirs.

A clear proof that this is so might be drawn from a discussion of the generalized curves, which represent the mean of observations at any locality when the series covers a full cycle of rise and fall. For, if some of the hydraulic conditions, especially the one which defines the origin of the curves, undergo change during the season of observations, it is easily seen that the generalized curve or formula expressing the mean of conditions will not be reconcilable with the conditions that are continuous. The Commission has shut out the opportunity for such a discussion by withholding their local discharge formulas from publication.*

* Discharge equations are the product of two factors, an expression for area of cross-section and one for the mean velocity in that section.

The function expressing area has its origin at the lowest point in the section, and would usually be complex, but, since the part of any section which lies below the lower limit of stage variation is, by the fundamental hypothesis of a discharge equation, considered as a constant, the form of that part of the section is of no consequence. Between the limits of stage variation many river sections may, without sensible error, be considered rectangular. Hence, A being total area, W width, g height above lowest stage and a constant area, the area expression is:

$$A = Wg + a.$$

Another line of evidence bearing upon the same point is afforded by series of stage observations made at stations which have been connected by leveling. The fall between stations is found to increase and diminish in a way not to be accounted for except by the coming and going of bars acting as dams. The table below shows the changes in a piece of river in which no bar obstructing navigation has developed, but there is a widening, and then a very decided contraction, between the observation points and an unstable channel.

Diagrams 3 and 4 show that a and c changed greatly, and in such a way that enlargement of section (local) accompanied diminished velocity and discharge.

Analysis of discharge curves derived from the several series of observations made on the Mississippi and other streams shows that impaired efficiency of discharge follows wherever erosion and deposit are important in amount, whether the local result of change at the observation section is scour or fill. Hence, any influence which provokes or exaggerates silt movement is a cause of channel impairment, and cannot be a means of improvement.

If the banks are sloping the sum of the triangles at the sides will be measured by $\frac{d+e}{2}g^2$, d and e being the co-sines of the angles of inclination; a more general expression would therefore be, $W1$ being width at lowest state:

$$A = \frac{d+e}{2}\,g^2 + W1\,g + a = f\,g^2 + W1\,g + a.$$

The expression for mean velocity is commonly taken as a straight line,

$$V = b\,g + c,$$

in which b is a local co-efficient, and c the value of velocity, when $g = o$, or, as g is defined above, when the river is at its lowest stage. In practice the assumption of a straight line is admissible for high stages, but if applied to low stages will lead to an underestimate of velocity, and very strange conclusions.

There is at every section a level at which flow would cease, determined by the crest of some dam, bar or other physical feature. Logically and practically, for use at low stages, this level must be ascertained and made the origin of velocity, which may then be very closely represented by a hyperbola:

$$v = \left(\frac{A^2}{B^2}\,E^2 + A^2\right)^{\frac{1}{2}} \pm A,$$

in which A and B are axes of hyperbola and E elevation of surface above level of no flow.

A closer approach to observations is obtainable in the form,

$$v = \frac{D}{C}(E + C),$$

in which D and C are variables depending on E. To make up a curve or table of discharge, one of these expressions for v should be used, but for numerical solution applied to high stages, only the simple straight line may be used, giving for rectangular sections:

$$Q = Av = bwg^2 + (ab + cw)\,g + ac;$$

and for trapezoidal sections:

$$Q = Av = bfg^3 + (cf + bw1)\,g^2 + (ab + cw1)\,g + ac.$$

Co-efficients and constants in the factor expressions have, therefore, a plain physical significance, and afford tests of the continuity of conditions, especially of a, w and c, during a series of observations from which an equation has been derived.

VARIATION OF FALL AT ST. LOUIS.

Year.	Highest Stage.	Greatest Fall.	Lowest Stage.	Least Fall.	Range of Stage.	Range of Fall.	REMARKS.
1871	17'.70	1'.82	3'.38	1'.09	14'.32	0'.73	The stages and falls are not for the same dates, but near. The falls are not the greatest or least, but are chosen to present a mean for several days, to avoid the uncertainty which attaches to extremes. Distance between gauges, 3 miles.
1872	21'.90	3'.06	1'.90	1'.22	20'.00	1'.84	
1873	23'.90	3'.67	3'.87	1'.54	20'.03	2'.13	
1874	18'.40	2'.47	5'.62	1'.22	12'.78	1'.25	
1875	29'.80	3'.02	4'.00	0'.92	25'.80	2'.10	
1876	32'.06	3'.02	6'.80	0'.87	25'.26	2'.15	
1877	26'.55	2'.47	7'.50	0'.55	19'.05	1'.92	
1878	25'.75	2'.55	9'.00	0'.50	16'.75	2'.05	
1879	21'.15	2'.10	7'.70	0'.45	13'.45	1'.65	
1880	.....	.....	.....	....	.....	....	
1881	33'.65	3'.21	8'.60	1'.08	25'.05	2'.13	
1858	39'.98	2'.89	.....	....	.....	....	By flood marks. Distance, 3½ miles.

Another instance, strongly in contrast to that at St. Louis, is found between the mouth of Red River and Carrollton, La., 192 miles, in which no bar obstructing navigation exists. The range of fall is from 36 feet to 4. The variation at low stages is from 11 feet to 4, and this proves that shoals varying in number and position are developed and again removed. A very small fall, 4 feet, in so great a distance, since discharge is always considerable, is only possible when the channel is continuously deep. A large fall, 11 feet, in the same distance for a like volume, is only possible when the channel is broken into a succession of pools. Indications that rise and fall of shoals is a controlling hydraulic condition are therefore found at all parts of the river.

The question remains, are these changes great enough to exercise an important influence on flood discharge? The evidence on this point is direct and conclusive. Depths on bars have been noted by navigators and gauges have been read by reliable observers. Bringing these together for two bars will establish the fact beyond question. The bars taken are about 12 miles apart, with an unusually narrow piece of river between.

VARIATION IN HEIGHT REFERRED TO LOW WATER, 1879.

	Of Bullerton Bar.			Of Island No. 34 Bar.		
1874	from +4′.0 to −3′.5	range,	7′.5	from +1′.0 to +13′.2	range,	12′.2
1875	" +3′.1 " −5′.0	"	8′.1	" +2′.6 " + 7′.8	"	5′.2
1876	" +9′.3 " −2′.8	"	12′.1	" +5′.8 " − 3′.6	"	9′.4
1877	" +7′.1 " −5′.0	"	12′.1	" +0′.8 " − 6′.7	"	7′.5
1878	" +8′.8 " −4′.2	"	13′.0	" +7′.8 " − 3′.2	"	11′.0
1879	" −5′.6 " +4′.6	"	10′.2	" +3′.7 " − 6′.0	"	9′.7
1880	" −5′.5 " +3′.6	"	9′.1	" +7′.5 " − 6′.7	"	14′.2
	Extreme vertical range.....14′.3			Extreme vertical range.....19′.9		

The following is an exhibit of the effects of cutting out at Bullerton Bar between dates:

1875. Oct. 6, depth 6′.5, reference of crest to low water, 1879.... +3′.5
" Nov. 6, " 6′.5, " " " " ....−2′.1
Cutting down of bar in 31 days..... 5′.6

1877. Aug. 24, depth 6′.0, reference of crest to low water, 1879... +4′.6
" Sept. 7, " 6′.5, " " " " ...−0′.8
" " 26, " 5′.5, " " " " ...−0′.4
" Oct. 10, " 7′.0, " " " " ...−4′.3
Cutting down of bar in 47 days..... 4′.8

1879. Sept. 21, depth 6′.5, reference of crest to low water, 1879..−1′.4
" Oct. 20, " 6′.5, " " " " ..−4′.9
Cutting down of bar in 29 days..... 3′.5

Several of the years named in the foregoing statement were not flood years; hence the filling up of the bars, which must have preceded the cutting out, could not have been a result, direct or direct, of overflow.

I have now proven that the rise of bars is a notable feature in river physics. The facts, in detail, prove that the two bars compared rise and fall together in point of time, but unequally in amount; that the changes are in direct relation and in an obscure proportion to change of stage. The rise of bar is also proven by the records to begin long before the flood reaches the stage of overflow, and to continue after overflow has ceased; also the bar crest is raised higher if the flood continues

longer, and, conversely, the longer low stage continues the more the bar crest is lowered.

The filling and scouring, of which the bar changes shown above are indications, cause the shifting channel of the Mississippi and the ever-varying sand bars.

Geometric relations of cross-sections determine the fact of fill or scour. The direction of currents, together with the source and character of material, controls position and form.

No addition to the height of natural bank can bring relief to the alternating action which arises from varying width, but, obviously, just so far as heightened banks and concentrated flood volume serve to increase the velocity and scouring power during floods, they provide the material for greater development of bars both in height and extent.

If, now, it be considered that the Mississippi, flowing over a series of bars of varying height, is precisely the same, except in stability and size, as the mill stream flowing over a series of dams, it will be seen that to build up the bars or dams in height is to raise the river in its bed. The fact that man builds the dam stone by stone, and Nature the bars grain by grain, does not affect the result. On the other hand, to cut down the bars in height is to lower the river in its bed. In the Mississippi abundant facts show that raising the bars is the work of the high stage, and the higher the flood the higher the bars. Cutting out bars is the exclusive work of the low stage, and the longer the low stage continues the more complete its work. These offices of high and low stage are never exchanged.

With the rise and fall of the bars the flood plane, or the height on a fixed gauge which will be reached when a given volume is being discharged, will also rise and fall, just as the flood line of a mill stream is raised when a dam is built or lowered when one is taken out.

Differences of discharge for equal heights on the gauge amounting to hundreds of thousands of cubic feet per second have been measured. For example, at Columbus, Ky., on April 2d, 1858, stage being 32′.0 feet, discharge was 989 850 cubic feet per second. On July 1st and 2d, after the flood of 1858, at the same stage, the discharge was only 790 820 cubic feet. The difference, 199 030 cubic feet, is one-fifth of the larger quantity, and about equal to the greatest known discharge of the Upper Mississippi at Rock Island, and not far from the volume of the recent Ohio flood at Pittsburgh.

The variation of height on gauge for equal volumes will be illustrated by the following observations, also at Columbus, Ky.: December 15th, 1857, discharge was 1 061 480 cubic feet at a stage of 29 feet; June 29th, 1858, when discharge was 1 090 010 cubic feet, the stage was 36′.7, or 7′.7 higher, the latter after the passage of crest of the third flood wave of the season. Making allowance for the small difference of observed discharge, the variation in height was at least 7′.5 feet. Levees 7′.5 feet high would be accounted important, but this 7′.5 feet is only a difference, known to have occurred, of the height required to contain a volume less than two-thirds of the maximum discharge in 1882. The figures quoted are taken from Humphreys and Abbott; later observations made under the Commission confirm the fact of enormous differences.

It is thus made very plain that, so long as one has no means of knowing to what height bars may be built up by the action of successive floods, he cannot know to what height on the gauge a given volume of water discharge may attain. It is also seen that the reported height of flood affords no measure of the volume discharged.

In order that floods may be effectually restrained by levees, it is essential that the engineer know the maximum volume of water to be guarded against, and also that he be assured that a given volume will always be discharged at a given height. Both of these conditions are wanting to a successful solution of the Mississippi problem by levees.

Rise of bars to impede flood discharge and at a later date to obstruct navigation being the result of high stage action, it follows, that if a succession of floods occur without a prolonged low stage interval their effects will be cumulative.

Taking the known history of the Mississippi, there has been a slow, but decided deterioration of the navigable channel; therefore, there must be a slight preponderance, taking seasons as they come, of injurious high stage action over the restorative low stage effort. The concentration of flood water school of engineering, represented by the majority of the Commission, would add to the energy which now works evil, expecting that in some unexplained way evil, when intensified, will be transformed into good. Another school of engineering, which includes many who have had opportunity and inclination to study the facts, would aim to take a portion of the energy now working on the injurious side and transfer it to the beneficial. Though modest in expectation as

to the amount which can be transferred, when considered as a proportion to the whole, they hope to change the preponderance, and so put the river in the way of working its own improvement, instead of the present deterioration.

This school puts forward equalization of volume as a fundamental principle to be contrasted with, and opposed to, concentration of flood volume, and also to dispersion by outlets.

The Mississippi from the mouth of Red River to the Gulf illustrates the results of a partial equalization of volume. An equalized volume would be represented by the ratio 1 : 1. The range of volume in the above-named part of the river is approximately represented by the ratio 1 : 10. There is but one grand oscillation from low stage to high and return in a year. The river is stable in position, banks cave but slowly, no wide places develop, and the channel is deep.

Below the Ohio, as a contrast, the ratio of volume is 1:22. There are several great oscillations in a year ; the river is unstable in position, banks cave rapidly, wide places abound, and shifting bars obstruct the channel.

The equalizing influences which produce the contrast between the two localities are :

1. Elongation of flood waves in some relation to distance traversed; that is, increase of flood length measured by time, and decrease of height measured by gauge, as distance from source of flood increases.

2. The influence of large tributaries whose floods do not coincide in time with those of the upper river.

3. The reservoir influence of the St. Francis, Yazoo, Tensas and smaller swamp basins, also the absorption of overflow water by the soil, and its return to the river at low stages, that is, the rise and fall of the ground water line over thousands of square miles.

4. The depletion of flood volume by outlet channels, of which the Atchafalaya is the chief.

The application of the concentration of flood volume principle would diminish the first of these by compressing the flood into less space and time. The second would not be affected at all. The third and fourth would be entirely suppressed.

It is admitted (see Report for 1883, page 22), that the range of volume in the lower river would be doubled by complete leveeing above and below Red River and closing the Atchafalaya. The greatest known

discharge past New Orleans, in the channel, is about 1 100 000 cubic feet per second; at mouth of Red River the flood of 1882 is estimated to have reached 2 200 000 cubic feet. To confine such a flood would be establishing at New Orleans the ratio 1:20 now found near the Ohio, and so a main cause of caving banks and shifting bars would be brought by professed works of improvements where it does not naturally exist.

Fortunately, the second equalizing influence is beyond the reach of interference, and the frequency of oscillation at the Ohio cannot be carried to the lower river, but, so far as the principle operates, it will tend to destroy the present favorable conditions.

This part of the river presents a favorable opportunity to test concentration of flood waters by levees, both by the facts of experience and by the rigid application of known principles to the comparatively simple conditions presented. An extended discussion is the more pertinent since the Commission has fairly stated the conditions, and has plainly intimated an intention to diminish the discharge of the Atchafalaya and to complete the levees along the Tensas front, and consequently "throw into the Mississippi a volume in excess of any known discharge." They add, page 22,* "While this increased volume would undoubtedly make "room for itself by ultimate enlargement of section, it could only do so "by the work of scour, the resistance to which would be indicated and "measured by increased slope or greater elevation of surface through-"out that part of the river while undergoing enlargement."

"Such additional service should not be imposed upon a region in "which have been adopted the measures necessary, under existing con-"ditions, for protection from inundation, without due preparation for "the increased height which will be given the floods."

To carry out this view, an item is inserted in the estimate, page 21, for levees "from Red River to forts below New Orleans," 279 miles. "The assumed mean height," now, "is 7 feet, to be raised to 9 feet. "Much the greater part of the addition would, of course, be made to "the upper part of the line." The proposition is, therefore, to build the existing levees higher.

The stated conditions, pages 21 and 22, are:

1. "This section of the river is in a state of much greater stability "than is found in any other part of its course below the junction of the "Missouri."

* To avoid repetitions, reference to the report for 1883 will be by page only.

2. "At a short distance below Red River it becomes narrower and "deeper."

3. "It has been leveed throughout for a great many years."

4. "No flood complications arise here, as above, from the return of "overflow water which has escaped from the river at points higher "up."

5. "Its bed, enlarged by levees, is fairly adapted to the drainage "which has hitherto been imposed upon it. By enlarged is meant in- "crease by vertical extension of the containing banks."

6. "Gauging at Carrollton in 1883 showed that the river was only "discharging as a maximum about 1 100 000 cubic feet per second, "while those at Red River Landing in the previous year showed that "double this volume, or 2 200 000 feet, found its way down the valleys of "the Mississippi and Red Rivers."

7. To the above I add, the levees are, as a rule, close along the banks of the river.

Complete concentration may therefore be expected to double the maximum volume now flowing in a practically stable channel, and involves first and necessarily a raising of flood level, to be held in control by levees. Without making any statement of the height expected, the Commission makes an estimate based on an assumed height of present levees, and an assumed mean addition of 2 feet. The reasonableness of this assumption is in question, as is set forth in Gen. Comstock's separate views, pages 25 to 29. It is also asserted that the increased volume "will undoubtedly make room for itself by enlargement of section," but without any consideration as to how, or where, this enlargement must take place.

Will it enlarge the section? how? and where? are three very important questions.

In considering the probable increased height of flood, or its alternate, enlargement of bed, it is not only a fair, but the only possible, course to estimate the height to which existing levees must be raised in order to contain the whole volume, and then to estimate the amount of enlargement that must take place in order that the increased volume may be discharged at the present height of floods. If all the expectations of the Commission are realized, the final outcome will be a condition lying somewhere between the extremes so estimated.

In estimating the height on gauge required to discharge a given

quantity, no better way is known than to apply a discharge curve determined by actual observation at the locality. Such curves are available at the mouth of Red River, and at Carrollton, 192 miles below. Speaking of such curves, the Commission says, page 17: "It is fairly inferable from this, that if the conditions under which a certain curve "representing the increment of velocity and discharge *while the river* "*was still within its banks* was developed, were continued, the form of "the curve throughout its upward extension would be maintained, and "that the additional height required for levees to restrain maximum "floods would be less than that computed alone from a consideration of "the increase of volume."

To illustrate what the Commission means, and to show the force of the begged concession which I have italicised in the above quotation, and for this once propose to allow, I present 4 discharge equations for the river near Carrollton, and also refer to diagrams 3, 4 and 5, Plate XLV, representing the two which will be mentioned last, and illustrating their meaning in the physical problem:

1. Is an equation derived by Maj. Charles R. Suter, member of the Commission, from observations selected from the 32 made at Labarre base, above Carrollton, in 1880; g = gauge, reading:

$$\text{Area} = A = 1799\,g + 131209.$$
$$\text{Mean velocity} = v = 0.2832\,g + 1'.764.$$
$$\text{Discharge} = Q = Av = 509.5\,g^2 + 40332\,g + 231453 \qquad (1).$$

2. Was obtained by the writer, allowing equal weight to all of the 32 observations:

$$\text{Area} = 2567\,g + 129120.$$
$$v = 0.2931\,g + 1.738.$$
$$\text{Discharge} = 752.4\,g^2 + 42306\,g + 224410 \qquad (2).$$

3. Obtained by the writer from all the 148 observations of 1883 at Cambronne base at Carrollton:

$$A = 1948\,g + 149704.$$
$$v = 0.293\,g + 1.222.$$
$$\text{Discharge} = 571.g^2 + 46244\,g + 183000 \qquad (3).$$

4. Derived by the writer from the first 20 observations in 1883, represents the conditions existing January 27th to February 28th of that

year, when the river was not only within its banks, but the velocity, as seen in diagram 4, much beyond its average value. The section above low water is treated as a trapezoid, with side slopes 14 to 1, extending indefinitely upward :

$$A = 14\,g^2 + 2135\,g + 136430.$$
$$v = 0.325\,g + 1.28.$$
$$\text{Discharge } Av = 4.55\,g^3 + 711.8\,g^2 + 47073\,g + 174630 \quad (4).$$

Assuming that all the estimated discharge in 1882, 2 200 000 cubic feet per second, is to pass Carrollton between levees occupying the position of those now existing, the heights would be by—

Equation 1	34.1	feet on gauge.
" 2	30.3	"
" 3	31.4	"
" 4	28.5	"

By equation 4 A would be 208 640 square feet and v 10.54 feet when $g = 28.5$. The highest stage on record is 15.9 feet.

Complete concentration on the hypothesis of stable condition of bed, which hypothesis is represented by the area equation of 4, would therefore raise the flood plane at Carrollton 12.6 feet.

At Red River Landing the discharge curve for the same volume indicates a rise to 59.8 feet, or 11.3 feet above the flood plane of 1882.

If, now, it be supposed, contrary to the teaching of the diagrams and of all other observed data, that the capacity of the bed, which is quite another thing than enlarged area, will enlarge so that the increased volume will pass without raising the flood plane, taken as at 16 feet on the Carrollton gauge, there is no reason to expect a materially greater mean velocity than is now found. Using equation 2 (the most favorable to levees of those allowing for variable section), present area at Labarre base at 16′ stage would be 170 250 square feet; mean velocity, 6.42 feet per second, and mean depth 64 feet. Allowing that when discharge becomes 2 200 000, v will become 7.33 feet, an area of 300 000 square feet will be required, or about 77 per cent. increase. Since depth is already 64 feet as a mean, there is slight ground to expect material deepening, but, if we allow that mean depth may become 75 feet, the width must increase from 2 700 feet, as now, to 4 000, a widening of one-fourth mile.

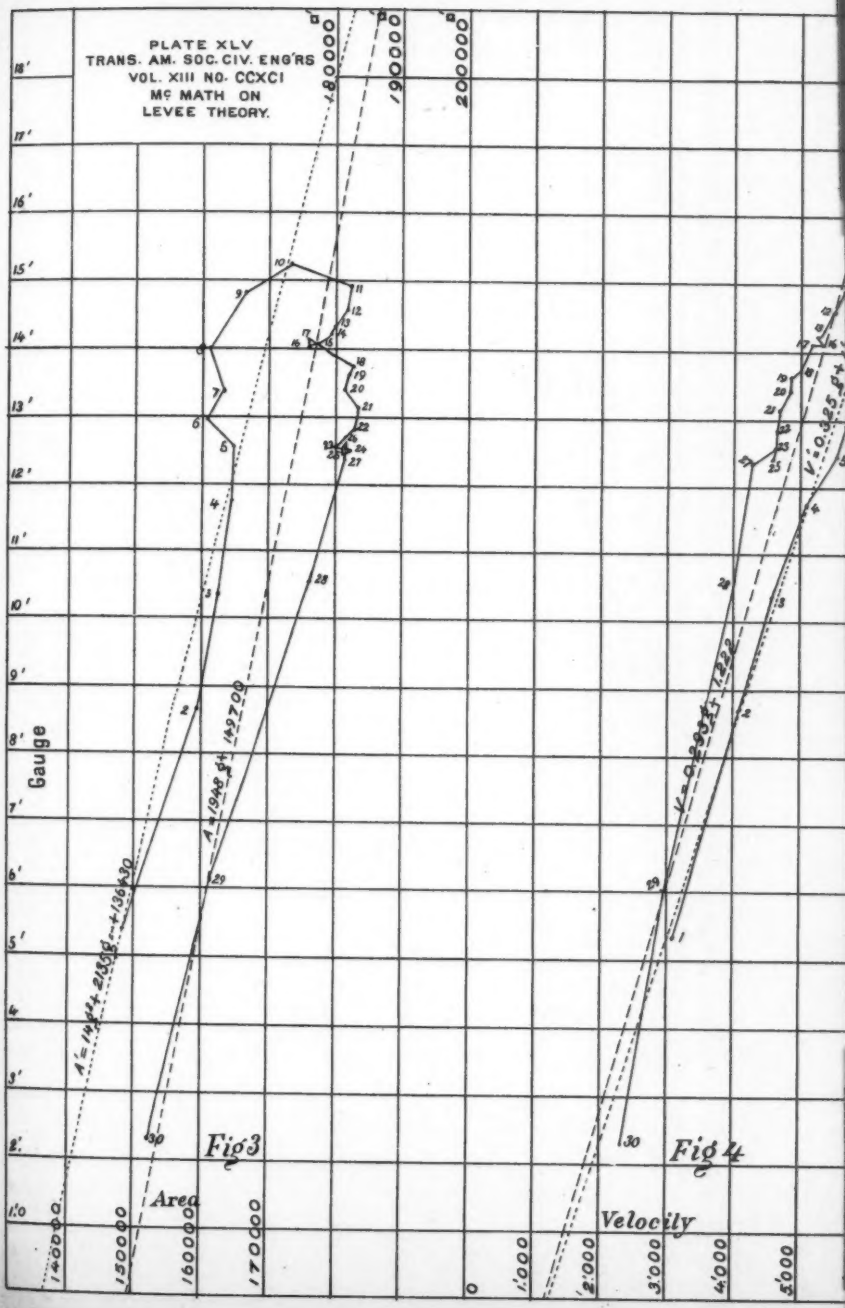
PLATE XLV
TRANS. AM. SOC. CIV. ENG'RS
VOL. XIII NO. CCXCI
Mc MATH ON
LEVEE THEORY.
Gauge
18'
17'
16'
15'
14'
13'
12'
11'
10'
9'
8'
7'
6'
5'
4'
3'
2'
1'0
A = 1948 S + 149709
A = 1948 S + 136480
V = 0.995 S + 1222
V = 0.925 S +
Fig 3
Fig 4
Area
Velocity
140000
150000
160000
170000
180000
190000
200000
0
1000
2000
3000
4000
5000

4'000
5'000
6'000
7'000
0
100000
200000
300000
400000
500000
600000
Vol
V=0.325 p+128
Fig 4

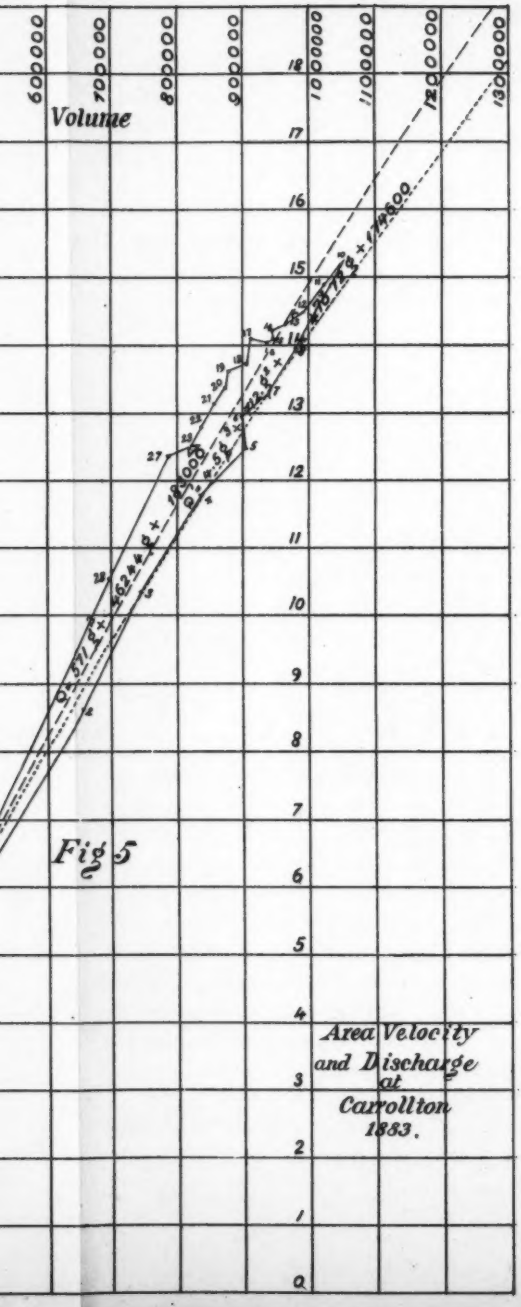
600000
700000
800000
900000
1000000
1100000
1200000
1300000
Volume
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
Area Velocity and Discharge at Carrollton 1883.

Fig 5

Take the possible alternatives, unchanged bed and added height, or unchanged height and bed enlarged, and which would be preferred? Or take any possible intermediate condition, and who would desire it?

But the above is still an incomplete view. It is only an attempt to answer how much change would be involved in the project. The manner how and place where of change remain to be considered. (In what follows, reference to any particular volume of flood discharge is dropped.)

It is apparent that to attain the condition under consideration, an enlarged bed and unraised flood-line, there must be, to provide enlarging force, a previous complete retention between levees up to some high standard, and those levees must be much higher than those now existing, consequently costly to construct and maintain, and always dangerous.

So far as the portion of river under consideration is concerned, we may conceive the concentration as effected at Red River, that is, the force which is to make the enlargement attains its full development at that point. The work to be done lies along the whole 295 miles to the Passes, and thence to the Gulf, and must be begun at the mouth of the river, and progress up stream; for no principle of practical engineering is more firmly established than that if one would clear out or enlarge an open water-course, by utilizing the current both for excavation and transportation, he must begin at the lower end. Otherwise, he must drive an ever-increasing mass of material before him, and to do so must carry the head, or height of flood, along with the work. This is impracticable; therefore a prime condition of successful enlargement is that the body of water be carried to the proper point of application, and that it shall not begin its erosive action until it arrives there. Levees may be built high enough and strong enough to convey the water, but no device or foresight can secure that erosion will not be begun too soon.

Is further illustration needed?

River men care little what may be occurring at the head of a channel or chute, but if it be enlarging or deepening at the foot, they expect an opening clear through. If it fill at the foot, its closure is sure. So in attempted or threatened cut-offs. Scour, as the water leaves the upper bend, is of no consequence, except to make a fill on the neck and defer the cut-off, but if a drain opens and enlarges at the lower bend, the cut-off is certain to be made. The argument advanced by the Commission itself against outlets, in the report of March, 1880, that a delta will be

formed in front of an outlet from the material carried out (and the more quickly as the enlargement at the upper end is greater to furnish material, Cubitt's Gap, for example), is a good description of what would occur in a channel enlarging from above.

The manner of enlargement is therefore a very important matter, and one which cannot be answered for.

The place of enlargement, at the bottom or sides of the original channel, is also something that should be known before entering upon such a project. I have already made a hypothetical distribution of it between lateral and vertical scour, assuming no more than that an action, equally free in several directions, will be distributed with approximate uniformity. This is more than fair to levees; for banks and bottom, while practically alike in being unprotected and unprotectable, and one might say in material also, present an important difference. Clay layers, when at the bottom, effectually resist abrasion by currents, but when exposed endwise, in a vertical caving bank, retard abrasion but little by their presence. (Humphreys and Abbott were not mistaken as to the existence of clay at the bottom of the river, but were as to the continuity and geological age of the clay.)

The existence of clay layers establishes a strong probability that, of a given enlargement, a great part will be obtained by widening. If any lateral erosion takes place, the levees now standing along the margin of the river must be broken, and no one, in the face of the amount of enlargement required, can say that they will be safe in any part. The levees required to effect complete retention cannot, therefore, be on the base now occupied, but a new system must be constructed far inland.

I make no point here of the fact that most of the buildings and the most valuable lands are close along the banks, and so endangered, if not devoted to destruction, by such a project. Nor do I care about the cost of building such levees. Neither is it now material whether the enlargement at any locality is likely to be wholly by widening or by deepening. My one question is: What disposition will be made of the material scoured, over 25 million cubic yards to the mile of river, and what will be the manner of its transport to its final position?

An answer to this question is not difficult. A volume of material equal to that of the enlargement must find its way to the sea, but in the movement there is every reason to expect that many times that volume will be disturbed, torn down and built up again, until by repeated

selections of the more easily transported material, the quantity is obtained.

For it is absolutely certain that so long as the river follows a tortuous course, its depth, both longitudinally and transversely, will be very unequal; and with equal certainty the heavier material, whether coming from local scour or brought from above, will not be carried continuously to the Gulf; but, as the swiftest current sways from one side of the bed to the other, the coarse and heavy particles will fall to the bottom. Granting that for every particle so falling an equal volume of lighter material is taken, there must be an accumulation of coarse matter at the bottom on crossings and at convex sides of bends. Erosion produced by concentration will therefore be, just like what is daily seen, located at the concave sides of bends, on both sides at straight places, and always resulting in increase in width at the latter, at the expense of depth. These processes, when begun, have no assignable limit; stable conditions have then given place to permanent instability.

The stable conditions now prevailing in this part of the river are the result of a partially equalized volume, that is, moderate range, 10 to 1, between maximum and minimum volume, and infrequent changes from one extreme to the other, and those occurring brought about gradually. Concentration of flood waters by levees would increase the ratio of extremes, and make the changes follow those of the great tributaries, which would increase the number and rapidity of fluctuations.

Concentration of flood water by levees is therefore proven to be a dangerous, yea a destructive expedient, in every aspect in which it can be viewed, when applied to that portion of the river which, by affording freedom from complication, is best adapted to it, if it were beneficial; failure here is failure everywhere. If the proof was less conclusive, and left a chance that it might be beneficial, we would still have the common sense question—Why disturb established favorable conditions for a bare chance that, in a readjustment, something more favorable may turn up?

I have presented overwhelming proof against levees, as applied to this section. On the other side, though "it has been leveed throughout "for many years," the best that could be said, after diligent study of the subject, was: "There is no evidence that the normal flood-line of the "Mississippi River, from Red River to the head of the Passes, except "where affected by cut-offs, is a fraction of an inch higher now than in

"1717, before the commencement of the levee system, but there is "evidence that it is not higher."*

By facts and reasoning, I have now tested the levee theory, and have shown its danger when applied to a particular part of the river. Not less pernicious would it be elsewhere in just about the degree of concentration, or augmented maximum, and increased frequency of flood.

* G. W. R. Bayley, in Trans. Am. Soc. C. E., No. CXXI, quoted by Committee on Levees and Outlets, Miss. Riv. Com. Rep., 1881, page 123.